Passive Localization of Multiple Sources Using Widely-Spaced Arrays With Application to Marine Mammals

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LONG-TERM GOALS

The long-term goal of our research is to develop systems that use a widely spaced hydrophone array to localize and track multiple unknown sources in shallow-water environments over long distances.

OBJECTIVES

The objectives of this project are: (i) Development of new theoretical frameworks for localization; (ii) Testing and fine-tuning of the theory and its implementation through simulations; and (iii) Application to whale data collected on widely spaced hydrophone arrays, including Navy arrays such as PMRF and AUTEC.

APPROACH

In all of our work, acoustic propagation models [1] are used as necessary.

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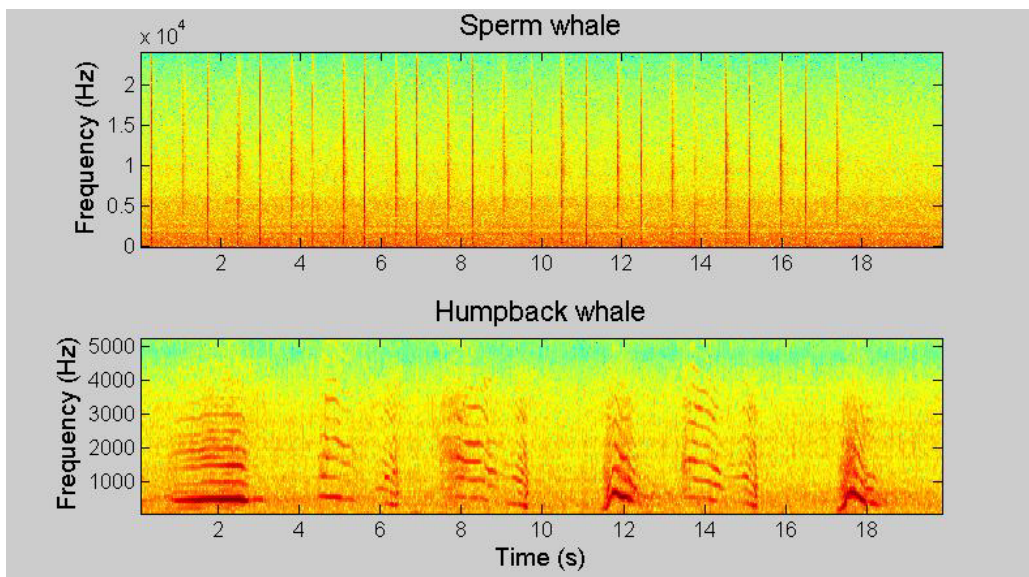Prescribed by ANSI Std Z39-18

***Figure 1. Spectrograms (256 point FFT Hanning windows with 50% overlap) of
typical sperm whale (top) and humpback whale (bottom) calls.***

Currently, two whale species are being considered for localization: humpback whales and sperm
whales. Due to differences in their calls, each species requires a different approach to localization.
Figure 1 shows spectrograms of sperm whale and humpback whale calls.

Sperm whales emit so-called "regular" clicks which are broadband (100 Hz – 20 kHz) short in duration
and predictable (Figure 1). These characteristics make sperm whales ideal candidates for time
difference of arrival (TOAD) methods [2] (also known as hyperbolic fixing methods). TOAD methods
use waveform or spectrogram correlation to estimate the difference in time of direct arrivals at
hydrophone pairs. To provide an alternate approach that does not rely on TOADs, we developed a
method that uses the difference in arrival times between direct and reflected arrivals (DRTDs) on
individual hydrophones [3]. Since DRTD is a function of source-receiver separation for a fixed
receiver and source at a single candidate depth, the DRTDs define circles around each hydrophone.
These circles indicate most probable source positions (see Figure 2). The candidate depth and point at
which receiver circles intersect most closely determines the estimated source position. The DRTD
method can be used in combination with TOAD methods to provide more precise source location
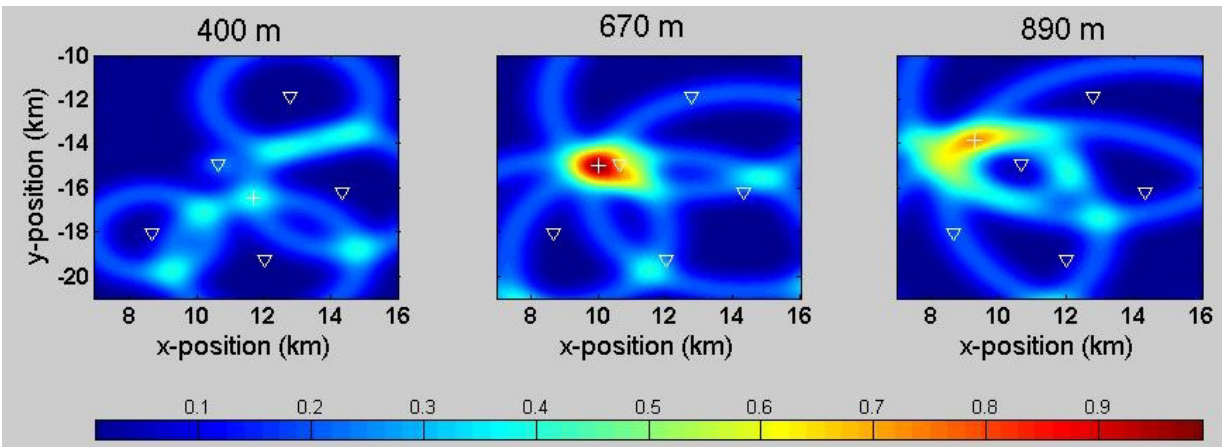estimates.

Figure 2. Likelihood surfaces created using our DRTD method for three candidate source depths (from left to right: 400 m, 670 m, and 890 m). Receiver positions are shown as white triangles. The best estimated source position is (10010 m, -15020 m, 670 m).

The humpback whale localization problem presents a considerably more challenging problem. Humpbacks are more difficult to localize because their calls (Figure 1) are highly varied, unpredictable, and of long duration (with individual calls of up to several seconds long) [4]. Humpback vocalizations are typically between 30 Hz and 9 kHz. In addition, they usually vocalize in shallow water, so multiple propagation paths must be considered. These characteristics may render hyperbolic fixing methods (and our DRTD method) insufficient, particularly in the case of multiple whales. Conventional matched-field techniques may also be insufficient because they are limited to low frequencies and/or rely on line arrays [5,6]. To deal with the unknown nature of the sources, we developed the pair-wise waveform (PWW) processor [7]. Our pair-wise spectrogram (PWS) processor [7] extends the PWW processor by using spectrograms instead of waveforms. Spectrograms allow us to use high frequencies, which are sensitive to environmental mismatch and noise.

The key individuals participating in this effort are L. Neil Frazer at the University of Hawaii and his Ph.D. student Eva-Marie Nosal. Both participants cooperate on all aspects of the work.

WORK COMPLETED

We developed and implemented the DRTD method. It was successfully applied to a dataset from the AUTEC range in the Bahamas. The work was reported in a paper in *Applied Acoustics* [3].

We developed and implemented the PWW and PWS processors. Due to high computational demand, our implementations were parallelized for use on supercomputers. Simulations were run for numerous environments and source/receiver configurations. The theory and initial simulations have been published in an *OES Newsletter* [7].

RESULTS

For sperm whales our DRTD method has a distinct advantage over TOAD methods in that it is not sensitive to receiver timing offsets. This advantage was emphasized during the 2nd International

Workshop on Detection and Localization of Marine Mammals, during which groups using TOAD methods could not localize the sperm whale source because of a 2.34 s receiver timing offset [8]. The DRTD method yielded an accurate whale track, which was similar to the track found by other groups after the timing offset had been discovered [8]. Figure 3 shows a 3D display of the resulting track.
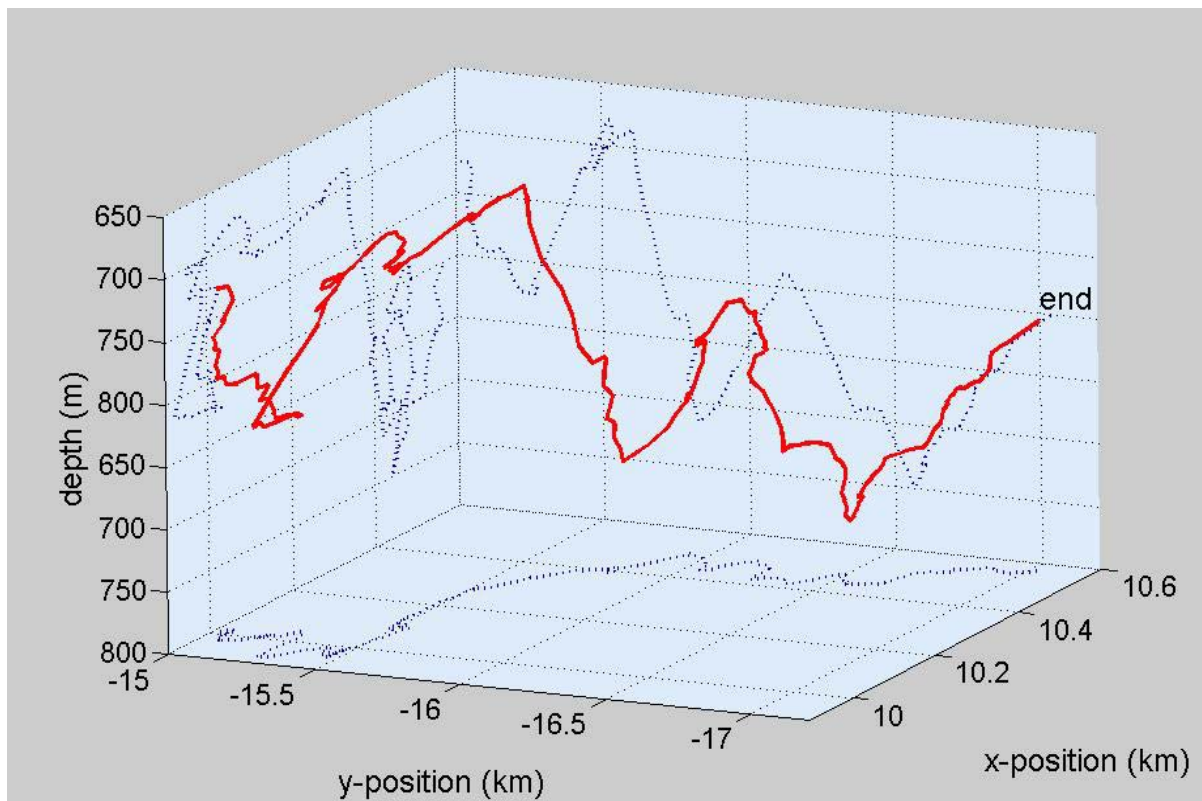

Figure 3. Three dimensional track of a sperm whale localized using the DRTD method and 5 bottom-mounted hydrophones in the AUTEC range. The track represents 25 minutes of data. Projections onto the three planes are shown with dotted lines.

For humpback whales our simulations indicate [7] that our PWS processor is more robust with respect to environmental mismatch and noise than the Bartlett (linear matched-field) processor and the PWW processor. This is as expected, since spectrograms are less sensitive to changes in the environment than waveforms. Comparisons of the Bartlett, PWW, and PWS processors are shown in Figures 4 and 5.
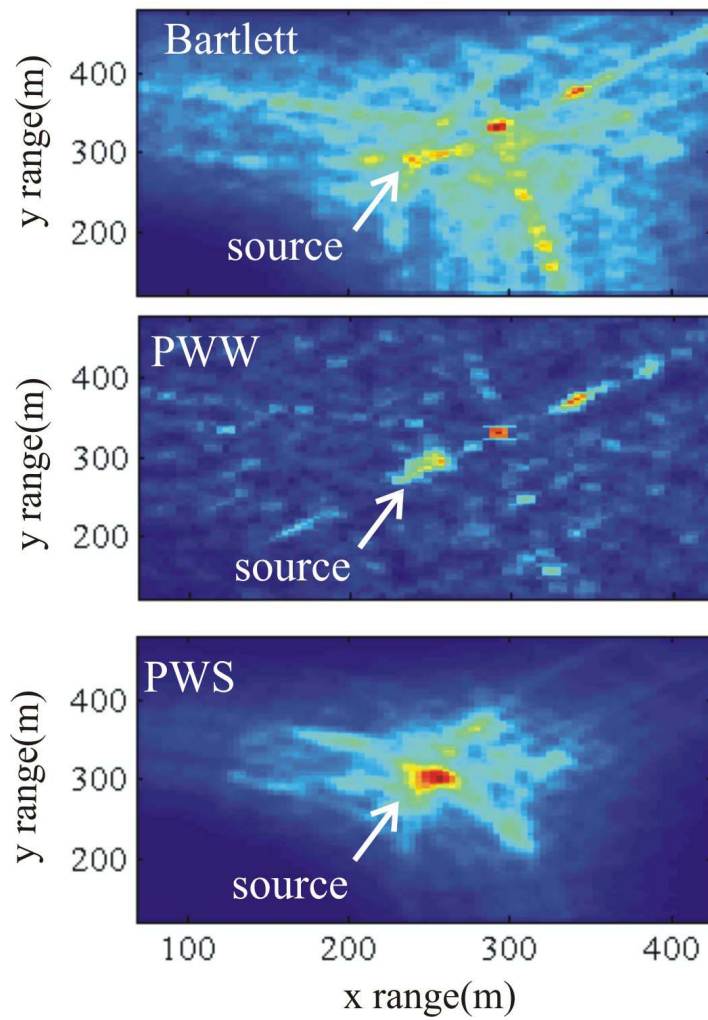
Figure 4. Ambiguity surfaces (probabilistic indicators of source location) created using the Bartlett (top), PWW (middle), and PWS (bottom) processors. Data was simulated for a single source, three receivers, signal-to-noise ratio of −5 dB. Environmental mismatch was simulated by using an incorrect bottom depth in the inversion (204 m instead of the correct depth of 200 m). Only the PWS processor correctly localizes the source.
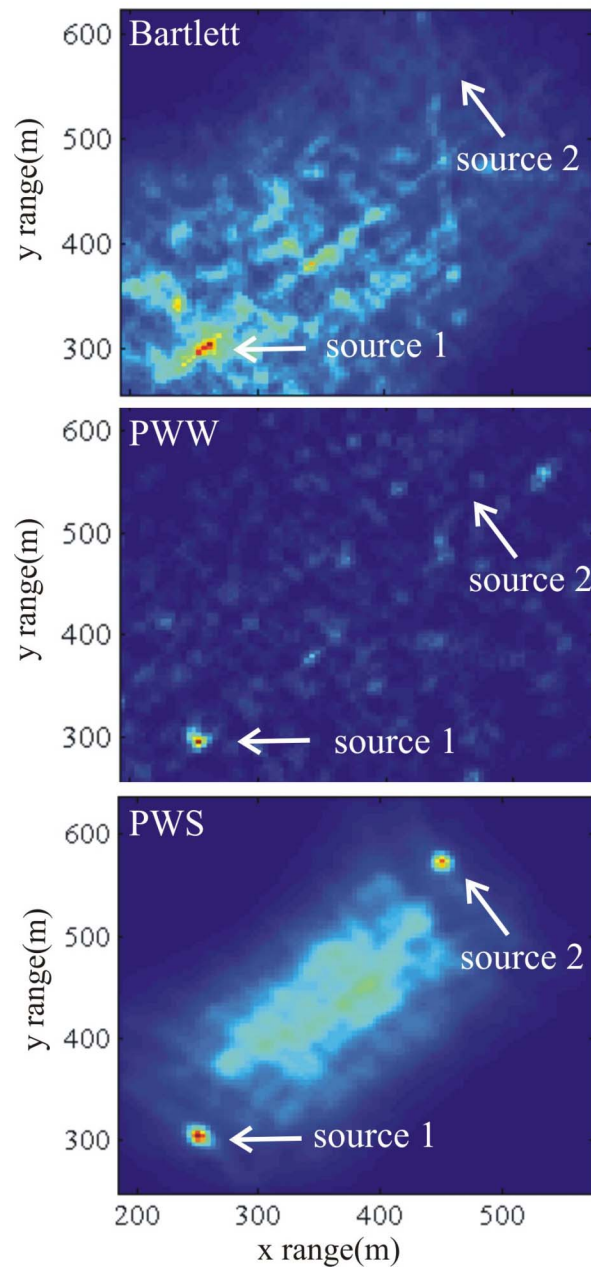
Figure 5. Ambiguity surfaces created using the Bartlett (top), PWW (middle), and PWS (bottom) processors. Data was simulated for two sources, four receivers, and signal-to-noise ratio of 0 dB. Environmental mismatch was simulated by using an incorrect bottom depth in the inversion (204 m instead of the correct depth of 200 m). Only the PWS processor correctly localizes both sources.

IMPACT/APPLICATIONS

The DRTD, PWW, and PWS processors are useful for monitoring, studying, and mitigating human impact on marine mammals. They may be also be used to monitor the ocean environment for other undersea and sea-surface sound sources.

RELATED PROJECTS

None.

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PUBLICATIONS

Nosal, E.-M., and Frazer, L. N., "Modified pair-wise spectrogram processing for localization of unknown broadband sources," IEEE Journal of Oceanic Engineering [submitted, refereed].

Nosal, E.-M., and Frazer, L. N., "Delays between direct and reflected arrivals used to track a single sperm whale," Applied Acoustics, 87 (11-12), 1187-1201, (Nov.-Dec. 2006) [published, referred]

Nosal, E.-M., and Frazer, L.N., "Pair-wise processing of spectrograms for localization of multiple broadband CW sources," Proceeding of the IEEE Oceans '05 Europe meeting, Brest, France, June 20-23 2005. Special publication in the Newsletter of the IEEE OES, Winter 2006 [published].

HONORS/AWARDS/PRIZES

First Prize to E.-M. Nosal (University of Hawaii) – IEEE OES Student Poster Program
Oceans '05 Europe, Brest, France, June 20-23, 2005. Sponsored by Thales Underwater Systems.

Student Engagement Award to E.-M. Nosal – Maui High Performance Computing Center (2005-2006).